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Optimized Stochastically Perturbed Parameterization Scheme for the Soil Temperature and Moisture within an Ensemble Data Assimilation System

Sujeong Lim[1,2*], Seon Ki Park[1,2,3], and Claudio Cassardo[4]

[1]Center for Climate/Environment Change Prediction Research (CCCPR), Ewha Womans University, Republic of Korea

[2]Severe Storm Research Center, Ewha Womans University, Republic of Korea

[3]Department of Climate and Energy System Engineering, Ewha Womans University, Republic of Korea

[4]Department of Physics and NatRisk Centre, University of Torino, Italy

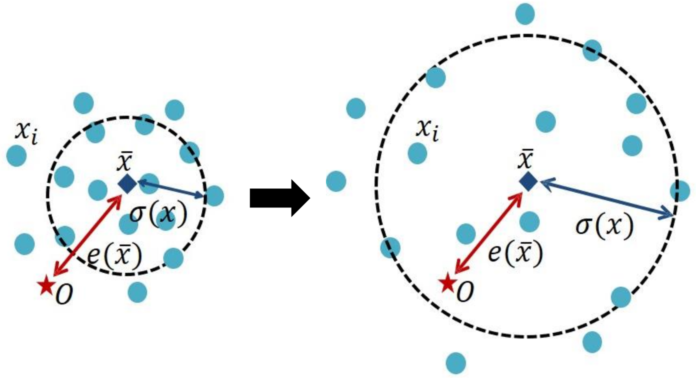
Motivation

- The ensemble spread represents the model uncertainties in the ensemble data assimilation (EDA) system.

- Generally, the under-estimated ensemble spread can cause the analysis to ignore the observation.

- This underestimation is also found in the coupled land-atmospheric modeling system, especially near the surface.

- The under-dispersive soil temperature and moisture can be a source of an underestimated ensemble spread of temperature and water vapor mixing ratio below the planetary boundary layer.



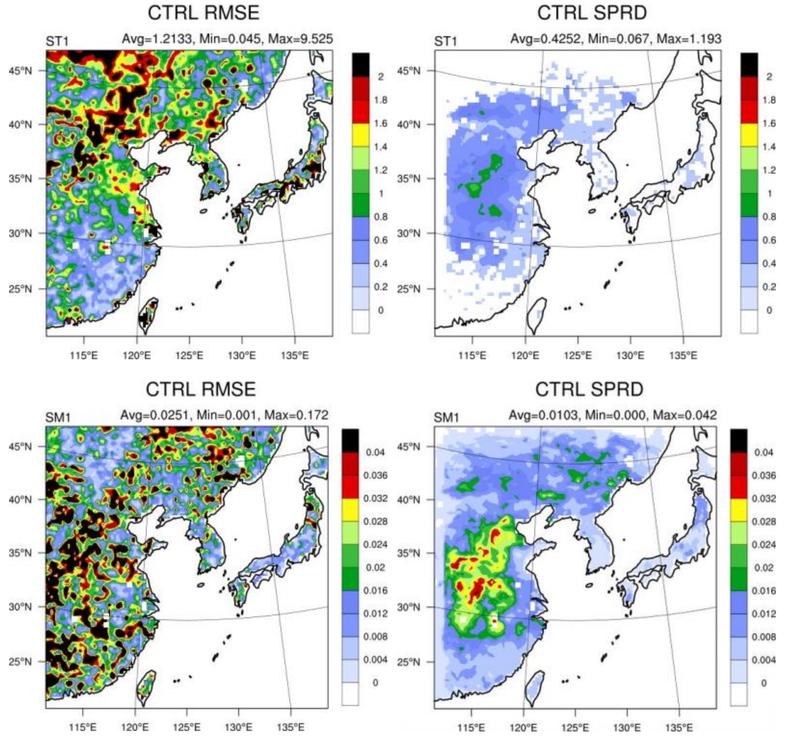


Fig 1. Schematic diagram of the ensemble spread: under-dispersive ensemble spread (left) and optimal ensemble spread (right).
Fig 2. RMSE and spread (SPRD) of soil temperature (ST) and moisture (SM) at the first soil layer in CTRL DA cycles.

Stochastically Perturbed Parameterization Scheme for the Noah LSM (SPP-Noah LSM)

- We perturb soil temperature (ST) or soil moisture (SM) using a spatially and temporally correlated random forcing at each grid point every time steps within the coupled WRF-Noah LSM system to represent the near-surface uncertainty.

$$\boldsymbol{x^1_{i,new} = x^1_i + r_i}$$

*** Tuning parameters**

- σ Amplitude
- L Decorrelation length scale
- τ Decorrelation time scale

x^1_i: ST or SM at the first soil layer (0 ~ 10 cm), i: ensemble member

r: Random forcing ($-\sigma \leq r \leq \sigma$) following Gaussian distribution with zero mean

(The perturbations sum up to zero so as not to introduce a systematic drift in the model)

❖ Additional prescriptions to the SM perturbing:

1) New SM falls within the respective bounds sets by the wilting point and the saturation level.
2) The perturbations in areas under snow cover or with frozen soil are set to zero.

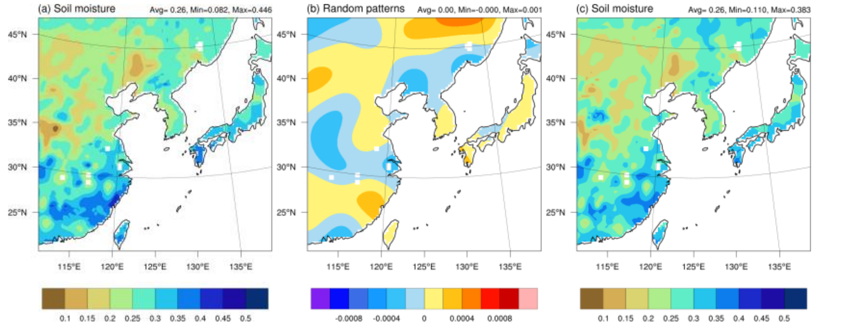


Fig 3. (a) original SM, (b) random forcing, and (c) new SM (m^3 m^{-3}).

Optimization of Tuning Parameters

- The micro-genetic algorithm (micro-GA) is based on the survival of the fittest to evolve the best potential solution over several generations; it is widely used for optimal parameter estimation.

- We have designed a fitness function using the normalized mean squared errors (NMSE) to evaluate the interaction between LSM and the planetary boundary layer (PBL) in terms of accuracy as:

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$$\boldsymbol{fitness\ function} = \boldsymbol{NMSE(x)} + \frac{1}{k}\sum_{z=1}^{k} \boldsymbol{NMSE(y_z)}$$

where $\boldsymbol{x}$ is ST (K) or SM ($m^3\ m^{-3}$), $\mathbf{y}$ is temperature (K) or water vapor mixing ratio ($g\ kg^{-1}$), and $\boldsymbol{z}$ represents the 850 to 1000 hPa vertical layers (k=7). The standard deviation of GFS analysis normalizes each MSE.

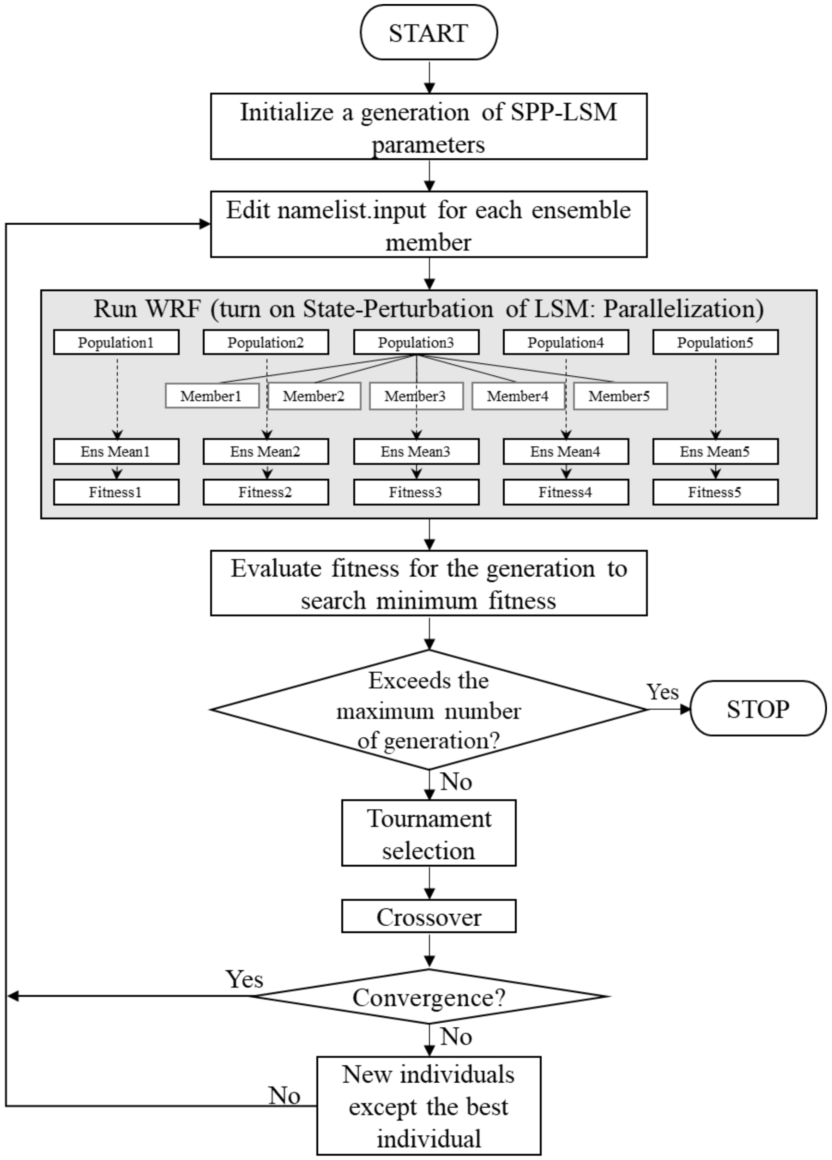

Fig 4. Flowchart of the coupling system of micro-GA and SPP-Noah LSM in the coupled WRF-Noah LSM.

Optimized Tuning Parameters and applications to EDA

Table 1. Optimized ST perturbations for daytime and nighttime (OSTP-D, OSTP-N). Same for the SM (OSMP-D, OSMP-N).

Tuning parameters	OSTP-D	OSTP-N	OSMP-D	OSMP-N
Amplitude	0.13 K	0.01 K	0.0003 m^3 m^{-3}	0.0003 m^3 m^{-3}
Length scale	2900 km	100 km	250 km	700 km
Time scale	120 s	900 s	900 s	120 s

- **Diurnal variations of soil variables**
- Physical interpretation
  - ✓ 2900 km: Solar radiation (domain size)
  - ✓ 100 km: Soil texture
  - ✓ 250 km: Mesoscale convective system
  - ✓ 700 km: Less convection

❖ Applications of SPP-Noah LSM to Ensemble Kalman Filter (EnKF) assimilating PREPBUFR (conventional data)

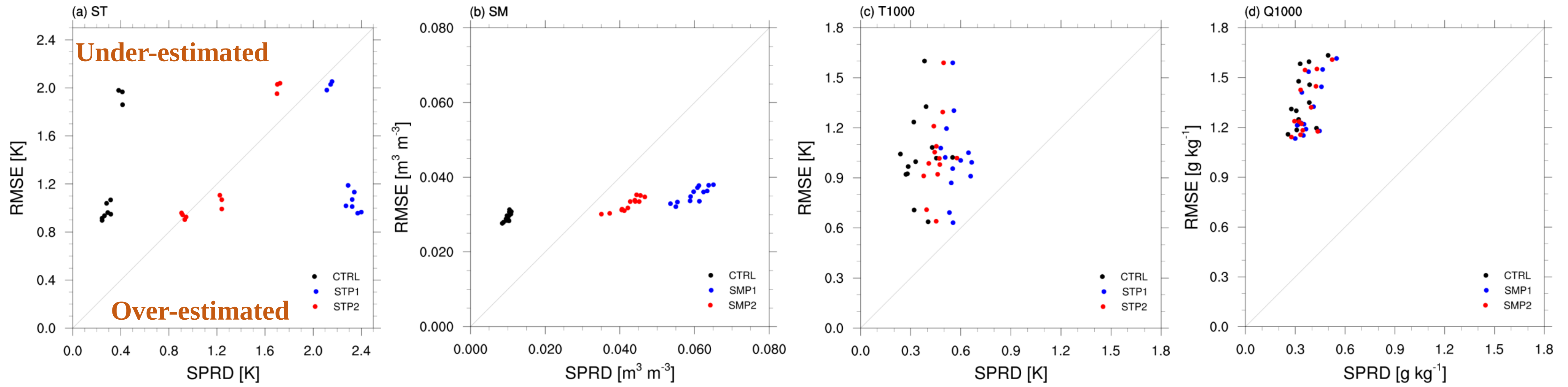

Fig 5. Scatter plots of the SPRD and RMSE for (a) ST, (b) SM, (c) temperature at 1000 hPa (T1000), and (d) water vapor mixing ratio at 1000 hPa (Q1000).

Applications of SPP-Noah LSM in EDA system

Background Error (Shading) & Analysis Increment (Contour)

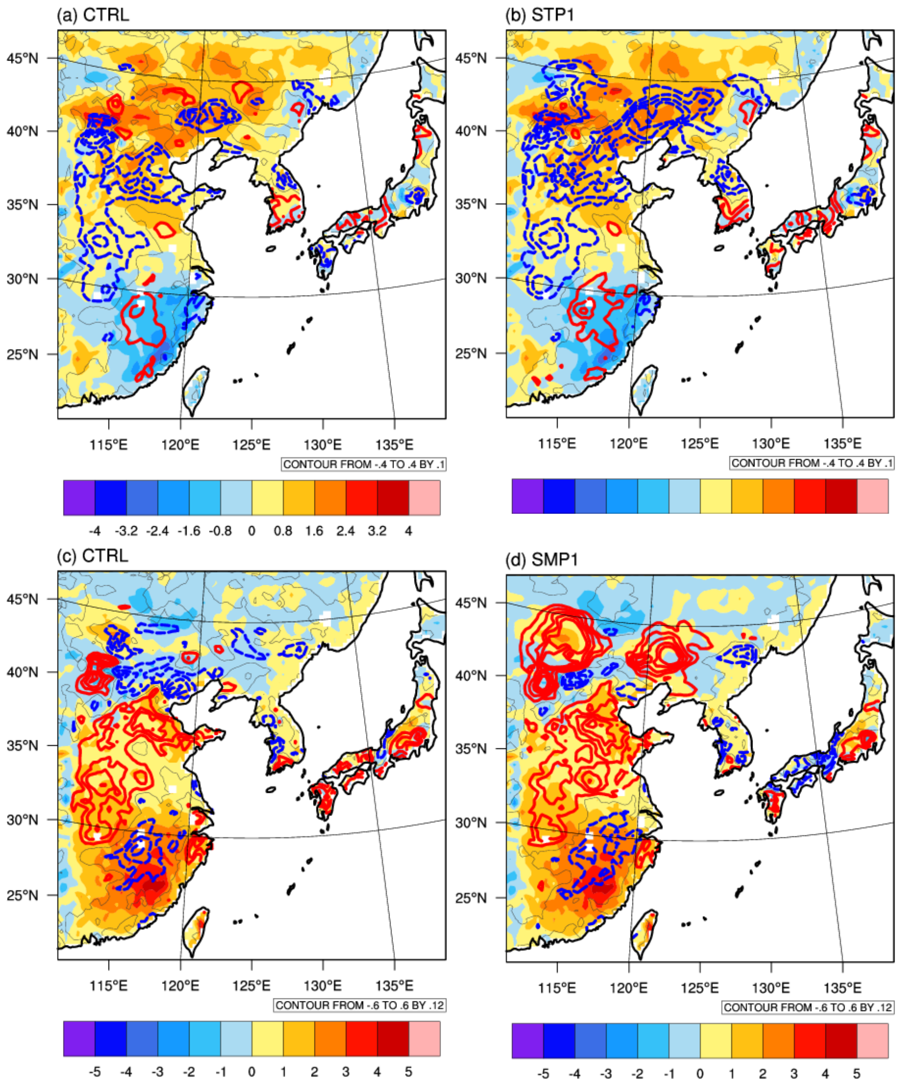

Fig 6. The analysis increment (colored contours; positive in red, negative in blue, and zero in gray) and the background error against GFS analysis (shaded) for temperature (in K) in (a) CTRL and (b) STP1 and for water vapor mixing ratio (in g kg^{-1}) in (c) CTRL and (d) SMP1. Results are averaged from 850 hPa to 1000 hPa.

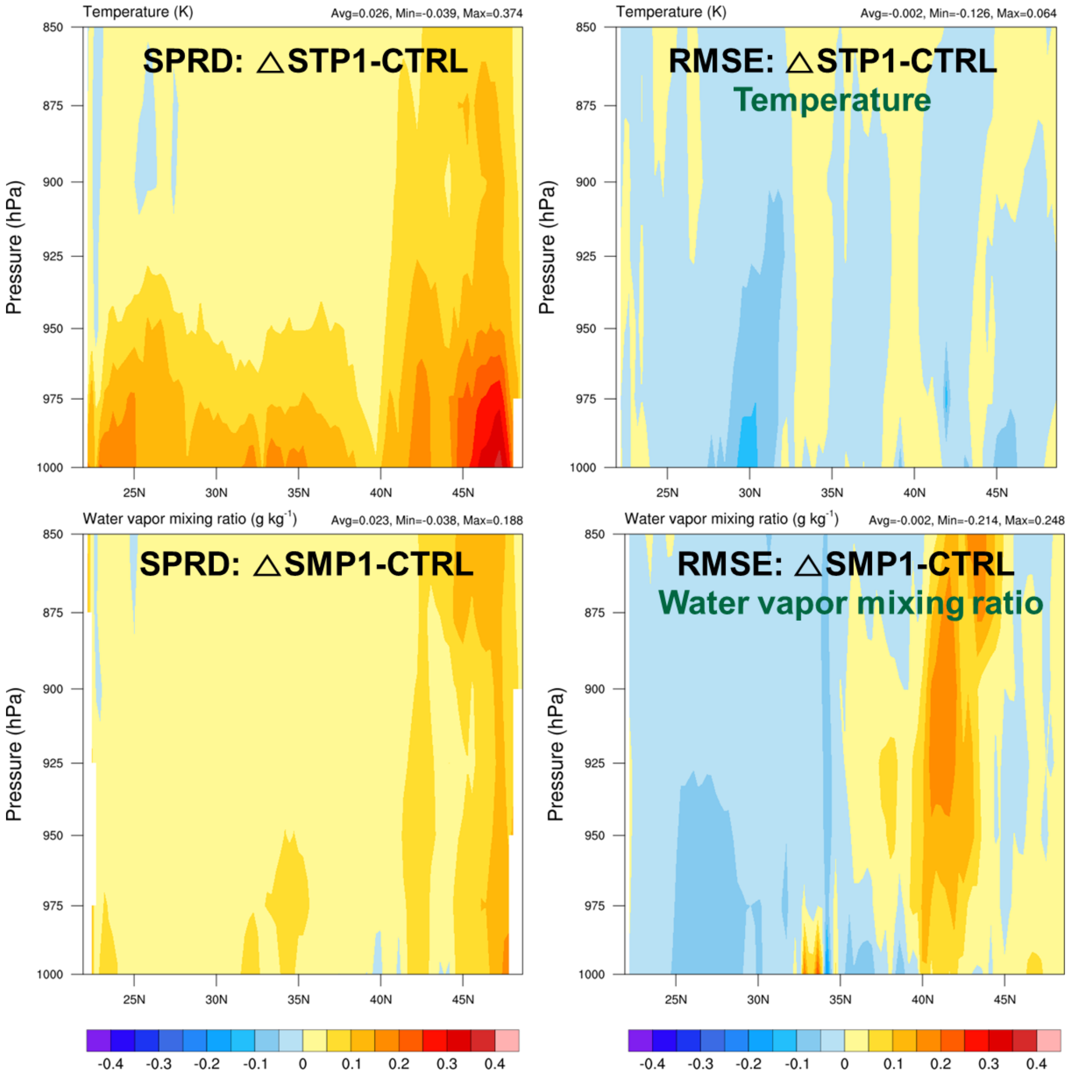

Fig 7. Δ zonal mean spread (STP1-CTRL) and Δ zonal mean RMSE (STP1-CTRL) for temperature (K) over the land (Top). Δ zonal mean spread (SMP1-CTRL) and Δ zonal mean RMSE (SMP1-CTRL) for water vapor mixing ratio over the land (Bottom).

Conclusion

- The stochastically perturbed soil temperature and soil moisture can indirectly inflate the ensemble background error covariance (BEC) of temperature and water vapor mixing ratio below the planetary boundary layer.

- The diurnally variated tuning parameters depicts a reasonable ensemble spread for soil temperature and soil moisture. However, the propagation to the atmospheric model is weaker than the single (e.g., daytime) tuning parameter.

- We plan to consider the heterogeneous characteristics of land use categories and soil types to improve optimal tuning parameters.